

## **Population Consequences of Acoustic Disturbance of Marine Mammals**

Erica Fleishman  
Bren School of Environmental Science & Management  
6832 Ellison Hall  
University of California  
Santa Barbara, CA 93106-3060  
phone: (805) 291-6258 fax: (805) 893-2578 email: [fleishman@bren.ucsb.edu](mailto:fleishman@bren.ucsb.edu)

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### **LONG-TERM GOALS**

The long-term goal of this project is to improve understanding of how effects of marine sound on marine mammals transfer between behavior and life functions, and between life functions and vital rates. This understanding will facilitate assessment of the population-level effects of anthropogenic sound on marine mammals.

In 2005, the U.S. National Academy of Sciences convened a National Research Council (NRC) committee that examined how the behavior of marine mammals responds to anthropogenic sound. The committee provided a conceptual framework to structure future studies of the potential population-level effects of changes in behavior of marine mammals. Developments since the committee issued its report, and advances in research that were not considered explicitly by the committee, made it possible to transform the conceptual framework into a more formal model structure. In particular, evolutionary biologists developed an approach for investigating trait-mediated interactions, which describe how the behavior of individuals affects the dynamics of interacting populations. Additionally, new developments in computationally intensive analytic methods made it possible to fit trait-mediated interactions to empirical data with techniques such as hierarchical Bayesian analysis.

The NRC committee identified several levels at which anthropogenic sound may affect marine mammals, including behavior (e.g., diving, resting, orientation), life functions (e.g., feeding, breeding, migrating), vital rates (e.g. adult survival, reproduction), and populations (e.g., growth rate, structure, extirpation). The Office of Naval Research is addressing the potential behavioral response of animals to sound exposure through controlled-exposure experiments. Knowledge of how effects transfer between behavior and life functions, and between life functions and vital rates, is limited. This project aims to improve theoretical and empirical understanding of transfer functions to help inform research and management efforts.

### **OBJECTIVES**

We have five major objectives for the project.

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1. To explore how the NRC committee's conceptual model of population-level effects of changes in behavior of marine mammals might be translated into a formal mathematical structure
2. To consider how the NRC committee's conceptual model might be parameterized with existing or emerging data on the responses of large vertebrates to disturbance
3. To define conceptual approaches for investigating transfer functions (e.g., time-energy budgets, trait-mediated responses)
4. To expand work by the NRC to include sensitivity analyses on different transfer functions
5. To outline exploratory models that might be used to model transfer functions, synthesize existing knowledge, examine potential mechanisms, or inform research and management efforts

## APPROACH

We convened a multidisciplinary research team of approximately 15 core participants. Additional participants are involved in some aspects of the work. Work will be conducted over approximately 29 months. The team meets in person approximately every 6 months (three meetings convened to date) to iteratively develop models, explore sets of data, address conceptual challenges and advances, and interpret model outputs, uncertainties, and applications. Participants conduct substantial work analytical work and writing at their home institutions between meetings. We sequentially are attempting to build models for elephant seals, bottlenose dolphins, baleen whales (especially North Atlantic Right Whales), and beaked whales. For the first two taxonomic groups, few appropriate data on acoustic disturbance are available. However, data are available on other behavioral disturbances that allow for increased understanding of how any disturbance may affect individuals and populations. A five-person steering committee [Dan Costa (University of California, Santa Cruz), Erica Fleishman, John Harwood (University of St. Andrews), Peter Tyack (Woods Hole Oceanographic Institution), and Mike Weise (Office of Naval Research)] provides oversight for the project as a whole.

The group is analyzing energy change during foraging trips by northern and southern elephant seals (*Mirounga angustirostris* and *M. leonina*) and the effects of this energy change on pup survival. Key participants are Jim Clark (Duke University), Dan Costa, John Harwood, Mark Hindell (University of Tasmania), David Lusseau (University of Aberdeen), Leslie New (University of St. Andrews), Rob Schick (Duke University), Lisa Schwarz (University of California, Santa Cruz), and Len Thomas (University of St. Andrews).

Schick and New are fitting state-space models of changes in body condition (lipid and lean body mass) over time during foraging trips made by elephant seals. New is using a Kalman filter to fit linear models, whereas Schick is using a Bayesian approach to fit nonlinear models. The next stage in the analysis is to apply the best-fitting models to data from additional southern and especially northern elephant seals to investigate the effects on body condition, pup survival, and colony dynamics of hypothetical disturbance that increases daily displacement or reduces the number of drift dives per day.

Schwarz is conducting a comprehensive analysis of tag loss in southern elephant seals. This analysis is a prerequisite for analyzing tagging data for northern elephant seals, similar to those available for southern elephant seals, to estimate the relation between pup weaned mass and survival.

Key participants in work on coastal bottlenose dolphins (*Tursiops* spp.) are Richard Connor (University of Massachusetts, Dartmouth), John Harwood, David Lusseau, Leslie New, Len Thomas, and Randy Wells (Chicago Zoological Society c/o Mote Marine Laboratory). The group is modeling four states (hunger, fear, condition, and need to socialize) for each individual. These states determine which activity of an individual is most likely in a particular time step. The overall activity of the school (traveling, feeding, resting, or socializing) is then determined by its mean motivational levels. The activity of the school affects the values of these states in the next time step. The activity of the school changes when more than 50% of the individuals are dissatisfied with the school's current activity. The model has been parameterized to mimic dolphins in Doubtful Sound, New Zealand, where some behaviors have only been observed in specific locations. Thus a school must travel to a new location before changing its current activity.

The model also describes the fission or fusion structure of bottlenose dolphin associations. In the model, an individual may leave its current school if two or more of its motivational levels have exceeded a specified threshold during the previous two time intervals. Tendency to leave is also affected by current school size (animals are more likely to leave small or very large schools). If an individual leaves, it will be accompanied by the individual with whom it associates most frequently.

The next steps are to refine the model structure and determine whether its parameters can be estimated on the basis of simulated data similar to empirical data from Doubtful Sound, Shark Bay, and Sarasota Bay. These data include time budget information from focal follows and information on individual respiration rates and surface intervals. The group discussed potential use of respiration rate, which might provide information on motivational conflicts within schools. For example, individuals whose state values indicate a preference for an activity that is different from others in the school are likely to have an elevated respiration rate.

Key participants to date in development of models for North Atlantic Right Whales include Chris Clark (Cornell University), Jim Clark, Peter Corkeron (NOAA), Phil Hammond (New England Aquarium), Scott Krauss (New England Aquarium), Rob Schick, and Peter Tyack. To model the effect of disturbance on their population dynamics of North Atlantic Right Whales, the group decided to implement a relatively mechanistic approach that uses data from D-tags to examine potential changes in feeding efficiency as a function of noise levels experienced by each whale. D-tag data from bowhead whales indicate that periods of active filtration can be readily identified from D-tag records. Additionally, it may be possible to quantify the amount of food obtained during filtration on the basis of the frequency with which the individual clears its baleen plates (which can be inferred from D-tag records). Evidence of such a relation could be used to quantify the potential effect of different levels of disturbance on feeding efficiency. This information could then be incorporated into a state-space model of changes in the health of individual whales from year to year.

If sufficient data on spatial and temporal variation in habitat use by individual whales and noise levels in these habitats are available, it may be possible to estimate the potential cumulative impacts of noise on each individual over the course of a summer. These estimates could then be used to inform an analysis of changes over time in the health of individual whales (see below). An alternative approach is to build an equivalent model that does not rely on D-tag data, but simply uses an estimate of the overall noise exposure of each individual as a covariate in analysis of changes in health from year to year. It may also be possible to use information on number of social groups as a measure of the amount of "free time" or lack of energy constraints that individual animals experience in different years.

The fourth meeting of the working group will be held in April, 2011, at the Atlantic Undersea Test and Evaluation Center (AUTECE) on Andros Island in the Bahamas. The objective of the meeting is to develop a model that is applicable to beaked whales. A fifth meeting, which will summarize all of the group's work and examine potential directions for future research, is anticipated for boreal autumn 2011.

## **WORK COMPLETED**

We have convened three meetings of the project team: from 28 September–1 October 2009 and 4–6 March 2010 at University of California, Santa Barbara and from 7–9 September 2010 at Woods Hole Oceanographic Institution.

## **RESULTS**

The best-fitting linear and nonlinear state-space models of changes in body condition (lipid and lean body mass) over time during foraging trips made by southern and northern elephant seals included similar covariates [stage of trip (outward, foraging, returning), maintenance cost, daily displacement, number of drift dives]. In nonlinear models, information on location of the ice edge has improved model fit for southern elephant seals. Tag loss in southern elephant seals is affected by the number of tags that have been applied and by a seal's age, sex, and weaned weight.

## **IMPACT/APPLICATIONS**

Improved understanding of transfer functions, whether theoretical or empirical, might help to guide research and management efforts, and to project how marine mammals will respond to alternative future scenarios of anthropogenic sound. Inferences also are directly relevant to assessing the potential effects on marine systems of climate change, changes in human density, and coastal development.

We anticipate that products and outcomes from the team's work, such as peer-reviewed publications and projected probabilities of extirpation or failure to recover to maximum levels of net productivity, will inform national and international legislation and scientific guidance on conservation status of marine mammals. Examples of these applications include the Endangered Species Act and the Marine Mammal Protection Act in the United States, the IUCN Red List categories and criteria, and the Species and Habitats Directive in the European Union.

## **RELATED PROJECTS**

Fleishman is leading a project on cumulative effects of underwater anthropogenic sound on marine mammals for BP Exploration. There is some overlap in participants between the groups, as well as open communication to maximize complementarity. To date, the cumulative-effects project has focused on individual-level effects. The ONR-sponsored project may provide a framework for evaluating how effects propagate to the population level.

## **REFERENCES**

National Research Council. 2005. Marine mammal populations and ocean noise: determining when noise causes biologically significant effects. The National Academies Press, Washington, D.C.